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SECONDARY DOMESTIC WASTEWATER TREATMENT USING A COMBINATION OF DUCKWEED AND NATURAL PROCESSES

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ABSTRACT

A small, two cell lagoon system receiving the waste from 51 homes is evaluated. The system uses a combination of minimal mechanical aeration, algal photosynthesis, and a mixed duckweed coverage of the family Lemnaceae for efficient, energy-conservative waste treatment. The yearly mean TSS and BOD_5 concentrations discharged from the system are 18 and 15 mg/l, respectively.

In addition, comparative data of duckweed collected from two sites is presented on their proximate, elemental, and vitamin contents as well as amino acid profiles.

INTRODUCTION

Using vascular aquatic plants to treat wastewater has proven to be an effective method for domestic sewage and industrial wastewater containing low concentrations of certain heavy metals and organics. Reviews on this subject have been prepared by Duffer and Moyer[1] and for the California State Water Resources Control Board.[2] Most of the work over the past few years in using higher plants to treat wastewaters have involved the water hyacinth (Eichhornia crassipes).[3-5] However, duckweed Lemnaceae have also demonstrated wastewater treatment qualities.

In a study by Harvey and Fox[6], Lemna minor effected 39% and 67% reductions in nitrogen and phosphorus, respectively, from secondary effluent. Sutton and Ornes[7] obtained maximum yields of 28 g dry weight/m^2·week with Lemna minor in secondary effluent. Phosphorus accumulation in plant tissue was directly proportional to the aqueous phosphorus concentration up to 2.1 mg/l. Sutton and Ornes[8] also followed the growth of Spirodela polyrhiza in sewage effluent. Culley and Epps[9] produced duckweed high in protein and nutrients when grown in wastewater. Culley et al.[10] published an extensive report on the use of duckweed for the improvement of a dairy waste lagoon system. Hillman and Culley[11] compiled the characteristics of Lemna for consideration in wastewater treatment.

In this paper, the performance of a secondary sewage treatment lagoon system with only duckweed is evaluated. In addition, the nutritional value of duckweed grown on domestic sewage is compared to that of duckweed collected from a natural water system.

DUCKWEED

The duckweed family Lemnaceae consists of small, floating, vascular aquatic plants whose frond lengths measure less than one centimeter in width. Duckweed is classified as the smallest flowering plant known. The Lemnaceae family is divided into four genera: Wolffiella, rootless with thin and sickle-shaped fronds; Wolffia, rootless with thick and globular fronds; Lemna which has fronds with single roots; and Spirodela which has fronds with two or more roots per frond. Duckweed are found essentially worldwide. In most instances, only mixed cultures of duckweed are found. Detailed descriptions of duckweed have been reported by Meunscher[12] and Hillman.[13]

Mixed duckweed populations can develop biomass densities over 1 cm deep. A standing crop of Lemna sp in fish ponds was estimated to be 1500 kg dry weight/ha.[14] Culley *et al.*[10] estimated that 17.6 m. t. dry weight/ha could be produced annually by mixed duckweed populations grown in wastewater lagoons.

Like many other plants, the nutritional value of duckweed reflects the nutrient content of its environment. Duckweed grown in sewage wastewaters, high in nutrients, have been found to have nitrogen and phosphorus concentrations in the dry plant tissue that range from 5.2-7.2% and 1.1-2.8%, respectively.[10, 11, 15] The reports above as well as others by Truax *et al.*[16] and Bhanthumnavin[17] contain information on the proximate and mineral composition of various duckweed species. However, detailed information on amino acid profiles, lignocellulosic components, and vitamin contents of duckweed has been lacking.

PART I. WASTEWATER TREATMENT

SYSTEM DESCRIPTION

A two cell lagoon system located at Cedar Lake Development in north Biloxi, Mississippi was used in this study. The system in Figure 1 has been in operation for 9 years and currently receives a mean influent flow rate of 52.8 m^3/day (14,000 gal/day) from 51 homes. The two cells operate in series.

The total capacity of the first cell is 1.8 times larger than that of the second cell. The first cell is also equipped with a floating 5 hp aerator. The original operating schedule for the lagoon system called for 24 hour operation of the aerator. In July of this study period, the aerator usage was reduced to only the night period in order to encourage algae to provide oxygen photosynthetically during the day and reduce the artifical energy demand.

The second cell is designed in a normal facultative mode due to its depth of 1.5 m (5 ft) and lack of external aeration. The duckweed, a mixture of Lemna, Spirodela, and Wolffia sp was introduced to this cell by natural means four years ago. During the study period, Wolffia was the dominant genus. Approximately 50% of the duckweed was harvested for the first time in April just prior to NASA's monitoring. No additional harvesting of the plants was done during the study period.

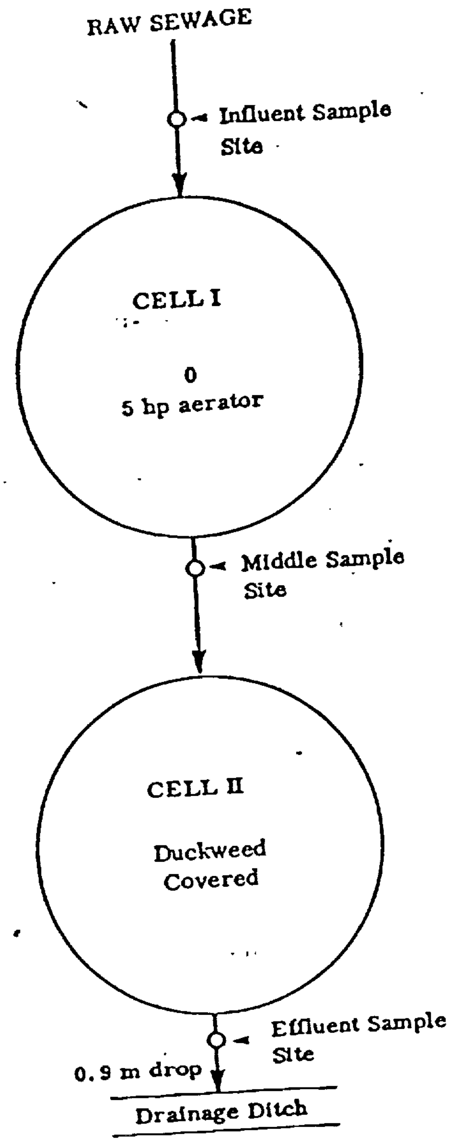
ANALYTICAL PROCEDURES

Grab samples were collected from the three sampling points indicated in Figure 1, twice a week during June, July, and August and once a week during the other months. The dissolved oxygen was measured in situ with a portable oxygen meter at the regular sampling sites and also at the drainage ditch which received the lagoon overflow following a drop of 0.9 m (3 ft). The effluent flow rate was measured with a calibrated weir at the point of discharge by the owners of the lagoon system.

The wastewater samples were analyzed for pH using a combination electrode, suspended solids using standard glass fiber filters to separate the filtrable and nonfiltrable residues, and 5-day biochemical oxygen demand (BOD_5) using the membrane electrode method to determine the dissolved oxygen concentrations according to Standard Methods.[18]

RESULTS

The 5-day biochemical oxygen demand (BOD_5) and total suspended solids (TSS) are the two most important parameters which any pollution control agency needs to assess the impact of wastewater discharge on receiving water bodies. The Cedar Lake maximum discharge concentrations for BOD_5 and TSS are 30 mg/l each. The mean data listed in Table 1 demonstrates the efficiency of the system. Except



DIMENSIONS	CELL I	CELL II
Surface area, ha	0.083	0.075
Depth, m	2.4	1.5
Detention time, day	36	21

FIGURE 1. Diagram of Cedar Lake Development Domestic Sewage Lagoon System

for the TSS in February, the system reliably upgraded the wastewater to meet secondary treatment levels.

The basic mode of operation of the system can be described in the following manner. The first pond is a settling pond with a large sludge accumulation capacity. Its depth and solids settling features enhance anaerobic digestion of the solid organic matter and dissolved organics and nutrients in the lower stratum. The surface is an aerobic stratum. Due to the high BOD_5 loading rate on the first pond, aerobic conditions must be maintained 24 hours a day at the surface to prevent odor emissions. Oxygenation of the surface stratum was effected by algal photosynthesis during daylight hours. A photo switch turned a floating, 5 hp mechanical aerator on at night. Significant energy savings were realized by taking advantage of the available natural processes without loss of treatment efficiency as noted in Table 1. Extrapolation of the yearly mean BOD_5 data with the yearly mean discharge flow rate given in Table 2 shows that the first pond removed an average of 95 kg BOD_5/ha·day (87 lb/ac·day).

The second "duckweed" pond is a suspended solids removal pond. The suspended solids discharged into the second pond were essentially algal cells. The thick duckweed mat provided a natural barrier to the sunlight. Therefore the algae died off and settled out of the water prior to discharge. The pond produced an effluent with yearly mean TSS and BOD_5 concentrations of 18 and 15 mg/l, respectively.

The other two paramters normally monitored in wastewater treatment are pH and dissolved oxygen (DO). Data on these parameters are presented in Table 2. The duckweed buffered the pH to a mean of 7.2. The pH buffering capacity of vascular aquatic plants has been noted with the water hyacinth.[3-5] The anaerobic effluent with a mean DO concentration of 1.0 mg O_2/l was oxygenated via the 0.9 m drop to increase the DO to 5.3 mg O_2/l.

TABLE 1. Monthly mean total suspended solids (TSS) and 5-day biochemical oxygen demand (BOD_5) of sampling sites designated in Figure 1.

MONTH	Mean Concentration, mg/l					
	BOD_5			TSS		
	INFLUENT	MIDDLE	EFFLUENT	INFLUENT	MIDDLE	EFFLUENT
May, 1979	201	64	20	178	225	10
June, 1979	213	64	28	194	172	9
July, 1979	142	33	13	224	98	12
August, 1979	160	13	10	291	74	8
September, 1979	173	20	17	246	132	22
October, 1979	171	15	8	173	96	19
November, 1979	264	29	10	159	63	11
December, 1979	280	27	15	186	66	15
January, 1980	115	28	15	127	67	21
February, 1980	153	27	14	150	63	33
March, 1980	180	39	24	203	50	29
April, 1980	103	13	11	89	24	29
Yearly Mean	180	31	15	185	94	18

PART II. NUTRITIONAL COMPOSITION

SAMPLING SITES AND ANALYTICAL PROCEDURES

In a previous study by these authors[4] with a domestic wastewater system receiving a high nutrient load, a mixed duckweed sample was collected and dried at 60°C in an oven to constant weight. Another mixed duckweed sample was collected from a pond receiving only artesian well water. The sample was prepared in the same manner. Both samples were sent to Raltech Scientific Services for analysis of proximate components, minerals, nutrients, amino acid profile, and vitamins. Lignocellulosic components of mixed duckweed was later obtained on another plant sample with a general nutrient content similar to that collected from the high nutrient environment. The crude protein was calculated as % kjeldahl nitrogen x 6.25. The total carbohydrate content was calculated as 100% - (% crude protein + % fat + % ash). The duckweed collected from the high nutrient environment is referred to us "Duckweed #1" and the low nutrient source as "Duckweed #2."

RESULTS

The duckweed grown in domestic sewage definitely contained superior quality biomass as compared to that grown in a natural pond. As seen in Table 3, sewage-grown duckweed contained 37.1% crude protein as compared to natural pond duckweed at 27.7%. The actual protein content of the sewage-grown duckweed as measured by the individual amino acids was 27.8% of the total dry plant mass. The actual protein was composed of well balanced amino acid contents as shown in Table 4. Most plant biomass is deficient in one or more essential amino acids, usually methionine and/or lysine. However the content of methionine and lysine of the sewage-grown duckweed extrapolated to grams amino acid/100 grams protein basis was acceptable according to the FAO Reference Pattern.[19]

The duckweed biomass was also high in the essential elements listed in Table 5. The sewage grown duckweed contained approximately twice as much phosphorus and potassium as the duckweed grown in artesian water.

TABLE 2. Monthly mean pH, dissolved oxygen (DO), and discharge flow rates of The Two Cell Cedar Lake Lagoon System.

MONTH	DISCHARGE FLOW RATE m^3/day	Mean Concentration pH INF	pH MID	pH EFF	DO, mg/l INF	DO, mg/l MID	DO, mg/l EFF[1]	DO, mg/l EFF[2]
May, 1979	52.2	7.3	7.7	7.1	2.8	6.0	1.5	5.5
June, 1979	40.9	7.5	8.2	7.1	1.4	3.7	0.6	5.2
July, 1979	58.3	7.3	7.5	7.2	2.1	3.1	0.8	5.0
August, 1979	46.6	7.3	7.8	7.0	1.0	4.5	0.6	5.0
September, 1979	48.5	7.5	8.1	7.5	2.3	3.3	0.4	5.0
October, 1979	40.9	7.6	7.7	7.2	1.9	3.5	0.7	5.1
November, 1979	45.4[3]	7.8	8.0	7.3	3.1	6.6	1.0	5.2
December, 1979	48.8[3]	7.7	7.9	7.4	3.9	7.2	1.7	6.0
January, 1980	67.8[3]	7.5	7.6	7.4	4.2	4.9	1.1	5.7
February, 1980	54.9[3]	7.3	7.5	7.2	4.1	6.4	1.3	5.4
March, 1980	79.5[3]	7.3	7.8	7.2	4.1	5.8	1.0	5.5
April, 1980	N/A	7.2	7.8	7.1	4.2	6.0	1.0	5.0
Yearly Mean	52.8	7.4	7.8	7.2	3.0	5.1	1.0	5.3

[1] Before drop

[2] After 0.9 m drop

[3] Limited data collected by Cedar Lake

N/A None Available

TABLE 3. Proximate composition of duckweed collected from two former experimental sites.

CONSTITUENT	Content, % Dry Weight	
	DUCKWEED #1	DUCKWEED #2
Crude protein	37.1	27.7
Fat	3.40	3.05
Fiber	15.6	11.8
Ash	12.5	12.0
Total carbohydrate	47.0	57.3
Actual protein	27.8	17.7

#1 = Duckweed grown in a domestic sewage lagoon
#2 = Duckweed collected from a natural pond system receiving no sewage

TABLE 4. Amino acid profiles of duckweed from two collection sites.

AMINO ACID	DUCKWEED #1	DUCKWEED #2	FAO REF PATTERN[19]
Alanine	6.88	7.28	
Arginine	7.99	6.82	
Aspartic	9.68	14.72	
Cysteine	1.70	1.30	
Glutamic	12.67	13.14	
Glycine	5.94	5.58	
Histidine	2.05	1.69	
Isoleucine	4.65	4.51	4.2
Leucine	8.89	8.35	4.8
Lysine	6.44	5.53	4.2
Methionine	2.16	1.86	2.2
Phenylalanine	5.69	5.13	2.8
Proline	4.81	4.57	
Serine	4.68	4.68	
Threonine	4.61	4.46	2.8
Tryptophan	2.10	2.36	1.4
Tyrosine	3.53	2.59	2.8
Valine	5.83	5.47	4.2

TABLE 5. Elemental composition of duckweed from two collection sites.

ELEMENT	Content/100 g Dry Weight	
	DUCKWEED #1	DUCKWEED #2
Nitrogen, g	5.94	4.43
Phosphorus, g	1.01	0.36
Potassium, g	2.13	1.22
Sodium, g	0.74	--
Calcium, g	0.88	1.34
Copper, mg	1.41	0.31
Zinc, mg	18.9	2.81
Iron, mg	145	14.3
Sulfur, g	0.85	0.45

Table 6. provides data on vitamin content which is not usually found in the open literature for any non-conventional plant food. The sewage-grown duckweed was particularly high in vitamin B-12 and niacin. Other plant constituents were the lignocellulosic components found in Table 7. Only duckweed grown in domestic sewage wastewaters was analyzed for these components. The total cellulose and hemicellulose content was 31.7% of dry weight. The lignin content of 2.72% was very low.

CONCLUSIONS

A properly designed and managed lagoon system such as the one at Cedar Lake using minimal mechanical aeration, algal photosynthesis, and duckweed in a polishing mode can produce acceptable secondary effluent. The first and second ponds in this study received BOD_5 loading rates of 115 kg/ha·day (105 lb/ac·day) and 22 kg/ha·day (20 lb/ac·day), respectively. The first pond reduced the initial BOD_5 by 83% to 31 mg/l. The TSS were reduced by 49% from a mean of 185 mg/l to 94 mg/l in the first pond. Of the TSS entering the second pond, the major portion was algal cells. The duckweed reduced the effluent TSS to a yearly mean concentration of 18 mg/l. The final effluent was clear and odor free. A single cell domestic sewage lagoon system operated in a facultative mode with only algae located near Cedar Lake was monitored the previous year.[4] This system when only vascular aquatic plants were present received a BOD_5 loading rate of 38 kg/ha·day (35 lb/ac·day) and discharged an effluent containing mean BOD_5 and TSS concentrations of 52 and 77 mg/l, respectively, for the 1978 monitoring period of July through November. In comparison, the Cedar Lake System is much more efficient due to its design and use of both vascular and non-vascular aquatic plants. Certainly the Cedar Lake System is very energy conservative and requires minimal day-to-day maintenance. In addition, the Cedar Lake System produces biomass high in nutrients and containing a well-balanced amino acid profile.

TABLE 6. Vitamin content of duckweed from two collection sites.

VITAMIN	Content, mg/100g Dry Weight. DUCKWEED #1	DUCKWEED #2
Riboflavin	2.64	1.88
Thiamine HCl	1.38	0.664
B-12*	53	26
Pyroxidine HCl	0.882	0.876
Niacin Bound	13.0	0.687
C	4.90	2.78
E (α-tocopherol)	6.9	10.9
Pantothenic Acid	5.50	2.79

*μg/100 g

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